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Some measurements of temperature and humidity near the sea surface

by

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1. Introduction

Because of the large proportion of the earth's surface that is covered by the oceans it is clear that the energy transferred from the oceans to the atmosphere must be an important factor in many meteorological problems. It is therefore desirable that our knowledge concerning the processes by which this transfer of energy occurs should be increased as much as possible. It is fairly certain that the form of the equations representing the vertical distributions of temperature and humidity overland will not usually apply over the open sea and information is lacking concerning the extent to which conditions over the oceans can depart from those of neutral stability. The importance of attempting to make actual measurements of the vertical profiles of temperature and humidity over the ocean is therefore obvious. More extensive discussion of this subject has been given by Charnock (1951).

The object of this paper is to describe a method of making such measurements and to indicate its possibilities by presenting a few results. The instrument used, for which Mr. J. MacDowall was mainly responsible, is described in some detail, although it might well be modified in the light of further experience. This account has been written without waiting for further observations because the instrument became unserviceable and, owing to pressure of other work in the Instruments Division, it may not be possible to make any further measurements for some considerable time.

2. Instrumental

(a) The apparatus

One of the major difficulties in measuring temperature and humidity at sea is that the presence of a ship introduces errors in the readings so that they are to some extent unrepresentative. If it is desired to make accurate measurements of the gradients of temperature and humidity near the sea surface such errors become prohibitive. It is therefore necessary to devise an apparatus with which the desired measurements can be made in the free air some distance away from and preferably to the windward of the ship. Such equipment has been developed in the Meteorological Office and is illustrated in Fig.1. It consists of a modified danbuoy the spar of which has been replaced by a hollow aluminium pole. This pole carries five aspirated dry and wet bulb thermoelectric psychrometers fixed at various distances above the waterline and four single thermocouples, for measuring sea temperature, at different levels below the waterline. A 60 lb. ballast weight is attached to the bottom of the pole to assist in keeping it vertical in the water. Each psychrometer is encased in a tufnol housing, painted white to reduce radiation effects (see Fig.2), each wet bulb element having a wick leading to a water

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reservoir. The thermocouple elements are similar to those used by Pasquill (1949). Ventilation is provided by two blowers driven by electric motors mounted in a watertight housing below the danbuoy and exhausting downwind through a rubber "snort" tube. Water traps are provided at the bottom of the mast and the "snort". The ventilation rate is controlled by a butterfly valve in each housing, the valves being set to give the same ventilation rate to each psychrometer. This rate is about 2.2 m./sec., when the lag coefficients of the dry bulb and wet bulb elements are about 70 seconds and 45 seconds respectively. Suitable cables, supported by floats, are used to carry power from the ship for the motors and to connect the various thermocouples to a switch which enables them to be connected in sequence on board to a potentiometer, an ice-junction being used as a reference. The heights of the elements above the water line in the 1956 trials of the equipment, the results of which are here presented, were 56, 89, 135, 195 and 287 cm. and the depth of those below the water-line 13, 30, 66 and 122 cm. There had been some earlier experiments in which thermisters were used as thermometer elements but difficulties were experienced due to calibration shifts.

(b) Operation and exposure

The complete apparatus, which has become known as a "thermobuoy", is launched from the stationary weather ship, to which it is attached by mooring lines as well as by the above-mentioned cables. It is allowed to float some 100 feet or so upwind of the ship and readily takes up this position as the ship drifts away from the thermobuoy under the action of the wind. The general arrangement is shown in Fig. 3. It has been found that the thermobuoy, as at present designed, floats in a vertical position in the open sea provided the wind is not much above force 3. It will be noted that although the buoy is upwind of the ship, the water in which it floats may well have been previously affected by the ship. It seems probable that this difficulty could be overcome by steaming slowly at right angles to the wind direction while observations are being made.

3. Observations

The apparatus was tried out successfully at sea from the O.W.S. "Weather Recorder" at station 'India' in July, 1956. Two sets of profiles which are believed to be reliable, and which have a number of points of interest, were obtained on the mornings of 6th and 9th July, 1956. Further sets were obtained on the 10th and 18th but during the first of these, conditions became unsuitable owing to increasing wind and sea and during the second some of the wet bulb readings were doubtful, dry patches afterwards being found on the wicks. The fact that at the next trial of the equipment, from the same weather ship on her next voyage in August 1956, both the cable and the electric motors were found to have become unserviceable also suggests that it is as well to reject the fourth set of observations made in July.

Having launched the thermobuoy and got it into position upwind of the ship, readings were taken as follows. Potentiometer readings were noted as pairs of thermojunctions were switched into the circuit in a fixed order, viz., first dry bulb junction at 287 cm. against reference junction in melting ice, then each of the other dry bulb junctions in turn against the first, then each wet bulb junction in turn against its corresponding dry bulb junction and finally each sea temperature junction in turn against the first dry bulb junction, proceeding in each case from the highest level to the lowest one. The cycle was then repeated. On 6th July the complete cycle was repeated eight times and took about 90 minutes and on 9th July it was repeated ten times and occupied about 115 minutes.

It was found that there were appreciable fluctuations of air temperature with time at all levels. The best way of dealing with the readings, which could not in any case have been taken simultaneously at all levels, was therefore to take mean values at each level over the whole run and regard these as giving approximate mean temperature and humidity profiles during the period of the observations. The results could be checked to some

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extent by comparison with the routine observations being taken on the ship for synoptic purposes and with the air and sea thermograph charts.

The results of the first set of observations with the thermobuoy are given in Table 1. Readings taken from the ship's meteorological logbook and as interpolated from the ship's air and sea thermographs are given in the bottom part of the table. It will be seen that the thermobuoy results are in general agreement with the observations taken on the ship and this consistency indicates that the equipment was working satisfactorily. A marked fluctuation in air temperature during the experiment was also clearly shown on the ship's air thermograph. The waves and swell varied the height of the buoy in the water over a range of about 25 cm. but it floated in the correct vertical position. After the experiment the ice standard and wet bulbs were in perfect condition.

The second set of results is given in the same way in Table II. On 9th July weather conditions were somewhat similar to those in the first experiment but the wind was lighter and recording conditions were much better because there was hardly any roll of the ship and the potentiometer could be read more accurately.

4. Discussion

The results set out in Tables I and II have been plotted against a linear scale of height in Fig.4 to show how the dry bulb, wet bulb, dew point and sea temperatures varied with distance from the sea suface. On both days the sea temperature was higher than the air temperature, as measured at the highest level, by between a half and one degree Fahrenheit and it would be expected that there would be an increase both in temperature and humidity as the sea surface was approached. It will be noted that the temperature rise is very slight; there is in fact a slight inversion between 56 cm. and 135 cm. in Fig.4(a) while in Fig.4(b) the whole increase amounts to less than two tenths of a degree. On both occasions the mean temperature at 56 cm. was considerably closer to the temperature at screen height on the weather ship (about 25 ft or 760 cm.) than it was to the sea surface temperature. The dew point profiles, however, show a more significant increase as the sea surface is approached. The increase is more marked in Fig.4(b) and this is consistent with the somewhat lighter winds on this day. It will also be noted that the observations are less scattered under the better recording conditions of 9th July.

The most striking feature of the results, perhaps, is the fact that the difference between the sea surface temperature and the dew point temperature only 56 cm. from the surface is a large fraction of that between the sea surface temperature and the dew point at the 287 cm. level (which is itself not greatly different from the dew point at the level of the ship's screen). On 6th July the dew points at 56 cm. and in the ship's screen were, respectively, 5.4 and 5.7 degrees below the sea surface temperature and on 9th July the corresponding figures were 6.6 and 7.7 degrees, so that even as near to the sea surface as 56 cm., 95 and 86 per cent, respectively, of the difference (see surface temperature - dew point at about 25 ft) still existed.

It will be noted that on both days the sea temperature profiles to a depth of 122 cm. were almost exactly isothermal. This is a little surprising because Houghton (1956) measured two profiles of sea temperature at station J during the summer of 1950 in somewhat similar weather conditions and found that the temperature at 122 cm. was appreciably colder than that near the surface, but the fact that his observations were made later in the day, at about 1430 G.M.T., may partly account for this and the somewhat doubtful exposure of the thermobuoy so far as sea temperatures are concerned may also be relevant.

In Fig.5 are shown, plotted on a logarithmic height scale, the profiles of $(t_o - t_z)$, where t_o is the sea surface temperature and t_z the temperature at height z cm., both for dry bulb and wet bulb temperature, and also of $(e_o - e_z)$, where e_o = .98 x the saturation vapour pressure in millibars at the sea

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surface temperature, .98 being a correction for salinity, and e_z the vapour pressure at height z. It is clear that the profiles are reasonably logarithmic, the fit of the second set being particularly good. The straight lines were fitted by the method of least squares and their equations found to be as follows:-

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Dry bulb	$t_o - t_z = .174 (\log_{10} z + 1.46)$
Wet bulb	$t_o - t_z = .233 (\log_{10} z + 11.98)$
Vapour pressure	$e_o - e_z = .192 (\log_{10} z + 9.53)$

9.7.56

Dry bulb	$t_o - t_z = .218 (\log_{10} z + 2.07)$
Wet bulb	$t_o - t_z = .866 (\log_{10} z + 2.78)$
Vapour pressure	$e_o - e_z = .621 (\log_{10} z + 2.65)$

It is well known that in neutral conditions the wind profile immediately over an aerodynamically rough surface can be expressed as

$$\frac{u}{u_*} = \frac{1}{k} \log \frac{z}{z_o}$$

where u_* is the friction velocity (defined by $u_* = \sqrt{\frac{\tau_o}{\rho}}$, where τ_o is the surface drag and ρ the air density), 'k' is von Karman's constant, and z_o is the roughness parameter which characterises the geometry of the boundary. Values of z_o for smooth sea at low wind speeds are now usually thought to be of order 0.02 cm. (Sutton 1955). Application of the general equation suggested by Charnock (1955) for the vertical profile of mean wind over a water surface to the mean wind speed of 6th and 9th July, respectively, gives values of z_o of about $10^{-2.8}$ and $10^{-3.4}$ cm.

If we refer to the intercept of the temperature or humidity profile on the log z axis as Z_o, by analogy with z_o, it is seen that there is some evidence that the values of Z_o and z_o were of the same order in these experiments over the ocean (e.g. on 9th July, 1956, Z_o was $10^{-2.1}$ cm. for temperature and $10^{-2.7}$ cm. for vapour pressure), and that in these near-neutral conditions the profiles of wind, temperature and humidity are roughly similar. Rider and Robinson (1951) demonstrated that profiles of temperature and humidity over land are roughly similar and it is of importance to test their conclusion over the sea surface under various conditions.

5. Conclusions

The thermobuoy apparatus is capable of giving valuable observations of temperature and humidity profiles near the sea surface, certainly if the wind speed is not much above 12 knots.

The accuracy of the measurements appears to be just about adequate but in view of the small gradients that have to be measured some improvement in this direction is desirable. On the other hand greater lag in the thermometer elements could probably be tolerated and might be helpful in reducing the effects of fluctuations and the need for so many readings.

Preliminary results indicate that profiles of temperature, humidity and wind are roughly similar. This is a matter of some importance and further observations are needed to confirm these results and to extend them to other wind and stability conditions. This could be done by similar measurements at ocean weather stations A, J, K and I. Simultaneous observations of the wind profile would be valuable but the difficulty in ensuring adequate exposure for the anemometers would be considerable.

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REFERENCES

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TABLE I - Observations taken at Station 'India' (59°N. 19°W.) on 6th July, 1956, 1040-1210 G.M.T.

(a) Thermobuoy observations

Height above sea, cm.	Mean dry-bulb temperature, °F.	Mean wet-bulb temperature, °F.	Mean dew point temperature, °F.	Mean sea temperature, °F.
287	51.23	48.55	46.18	
195	51.25	48.57	46.21	
135	51.41	48.63	46.18	
89	51.32	48.68	46.36	
56	51.23	48.70	46.48	
- 13				51.91
- 30				51.91
- 66				51.89
-122				51.90

(b) Synoptic observations at 0900 and 1200 G.M.T. included the following:-

G.M.T.	Dry-bulb	Wet-bulb	Dew point	Sea temp.	Cloud	Visibility	Wind	Waves	
0900	51.2	48.8	46.3	52.0	3/8 Cu 2,000 ft. 4/8 Sc 4,500 ft. Some Ac. Total 7/8	Over 12 mi.	200°/10 kt.	Direction Period Height	220° 7-9 sec. 5 ft.
1200	51.3	48.3	45.0	52.4	1/8 Cu 2,200 ft. 4/8 Sc 4,500 ft. 6/8 Sc 5,900 ft. Total 7/8	Over 12 mi.	200°/12 kt.	Direction Period Height	220° 7-9 sec. 5 ft.

(c) Air and sea thermographs indicated the following hourly values (corrected)

Hour	0900	1000	1100	1200	1300	G.M.T.
Dry-bulb temp.°F.	51.2	51.3	50.1	51.3	51.3	
Wet-bulb temp.°F.	48.8	48.6	48.4	48.3	48.2	
Sea temp. °F.	52.0	52.3	52.2	52.3	52.3	

TABLE II - Observations taken at Station 'India' (59°N. 19°W.) on 9th July, 1956, 1025-1220 G.M.T.

(a) Thermobuoy observations

Height above sea, cm.	Mean dry-bulb temperature, °F.	Mean wet-bulb temperature, °F.	Mean dew point temperature, °F.	Mean sea temperature, °F.
287	52.18	48.64	45.48	
195	52.18	48.74	45.69	
135	52.24	48.89	45.94	
89	52.26	49.06	46.26	
56	52.33	49.24	46.56	
- 13				53.15
- 30				53.16
- 66				53.15
-122				53.13

(b) Synoptic observations at 0900 and 1200 G.M.T. included the following:-

G.M.T.	Dry-bulb	Wet-bulb	Dew point	Sea temp.	Cloud	Visibility	Wind	Waves	
0900	52.2	49.0	45.6	53.5	3/8 Cb 2,000 ft. 6/8 Sc 5,000 ft. Total 6/8	Over 30 mi.	330°/3 kt.	Direction Period Height	340° 7-9 sec. 5 ft.
1200	52.7	49.0	45.0	53.6	2/8 Cb 2,000 ft. 4/8 Sc 5,800 ft. Some Ac. Total 5/8	Over 30 mi.	310°/9 kt.	Direction Period Height	330° 7-9 sec. 5 ft.

(c) Air and Sea thermographs indicated the following values:-

Hour	0900	1000	1100	1200	1300	G.M.T.
Dry-bulb temp. °F	52.2	52.1	-	52.7	52.7	
Wet-bulb temp. °F.	49.0	49.0	-	49.0	49.4	
Sea temp. °F.	53.5	53.5	53.5	53.6	53.7	

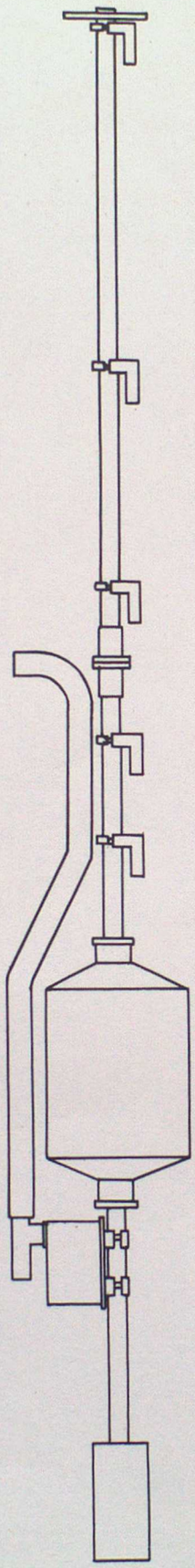

FIG. 1 SKETCH OF "THERMOBOUY"

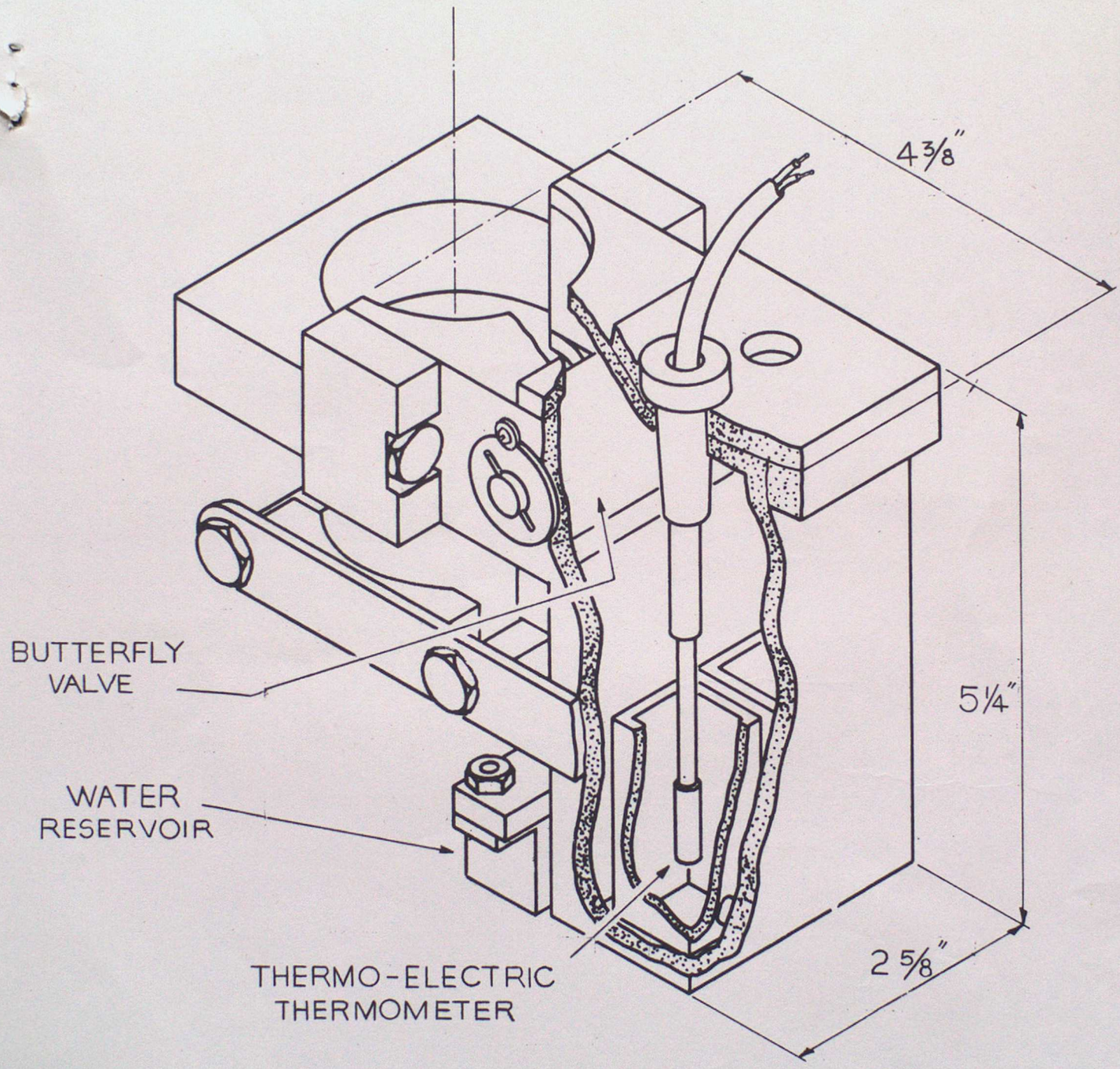

FIG. 2 DETAILS OF PSYCHROMETER HOUSING

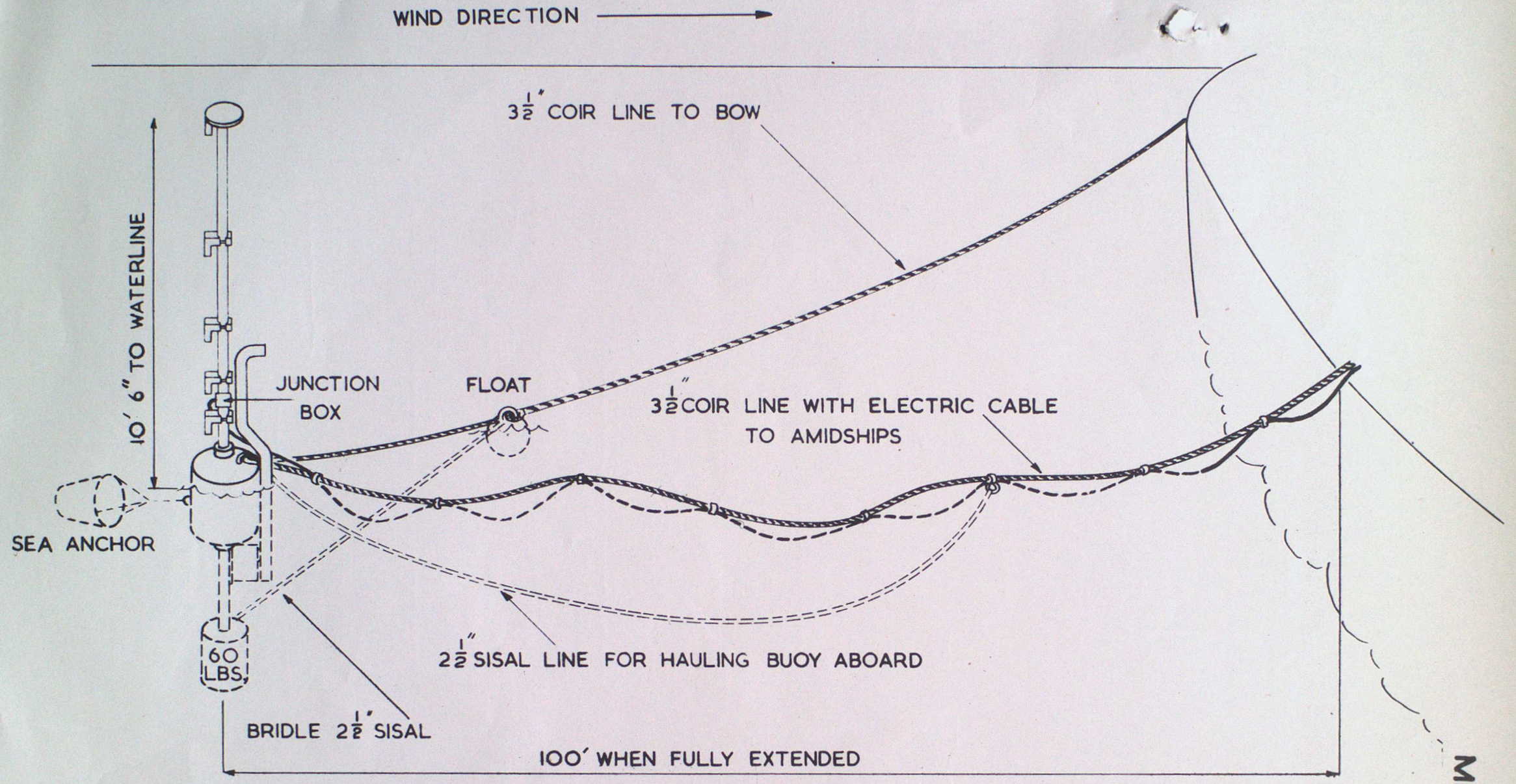

FIG. 3 GENERAL ARRANGEMENT OF "THERMOBOUY" IN OPERATION

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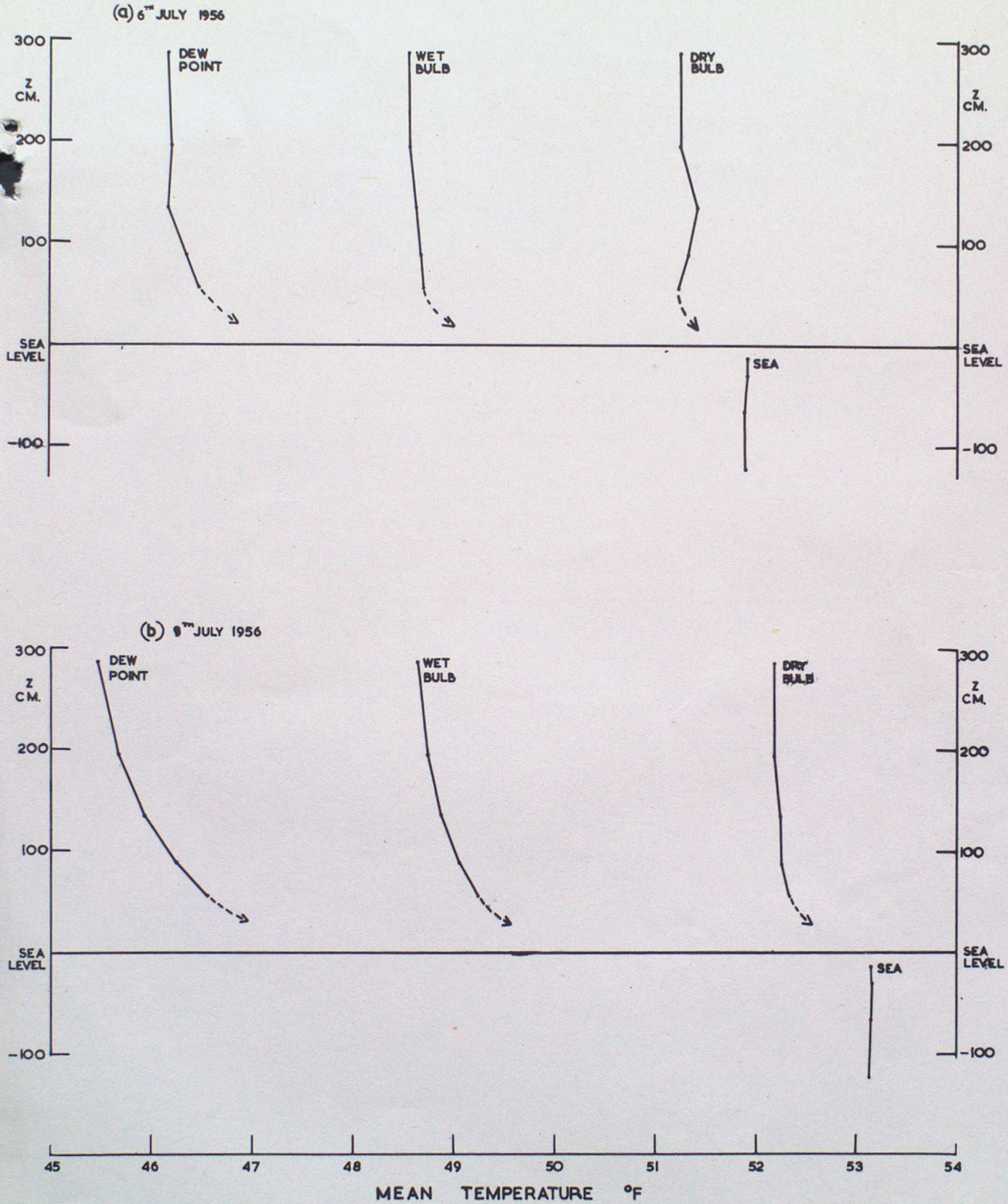
FIG. 4 PROFILES MEASURED AT O.W. STATION I ON 6TH AND 9TH JULY 1956



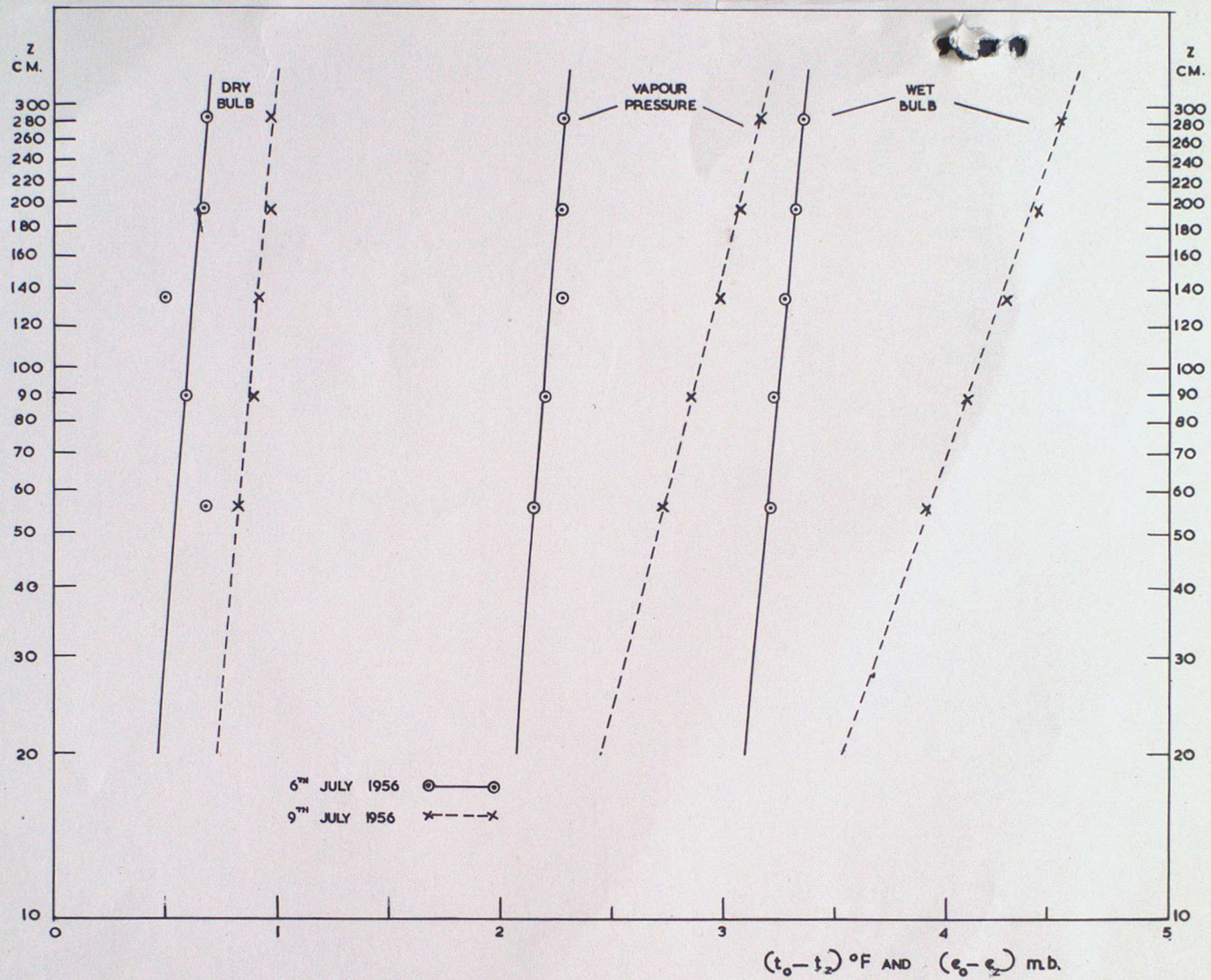


FIG. 5 PROFILES OF $(t_o - t_z)$ AND $(e_o - e_z)$ ON LOGARITHMIC HEIGHT SCALE

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